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Thermal Simulation Of Clamshell Heat Exchanger With Different Fluid Flows-A Study

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Abstract: **Clamshell Heat exchangers are used in the residential furnaces, for room heating purposes. The clamshell heat exchanger is subjected to heating and cooling cycles alternatively. The hot gases after combustion in the burner flow through the heat exchanger for 150 seconds heating the clamshell heat exchanger. This constitutes the heating cycle. The flow of hot gases from the burner is stopped after the completion of heating cycle. Now the cold air from the atmosphere is blown over the hot clamshell heat exchanger for next 150seconds. Thereby heating the air and cooling the clamshell heat exchanger. This constitutes the cooling cycle .In this process of heating and cooling in small time span of 150seconds, the clamshell is subjected to large thermal stress variations. These stress variations induce the thermal fatigue in the material and lead to formation of cracks in the clamshell heat exchanger. The heating and cooling cycles are simulated using the principles of Finite element methods and the analysis software ANSYS 15.0. Firstly, the transient fluid flow analysis of gas flow region is performed to plot the velocity, pressure and temperature distributions in it.**

The analysis carried out with 1.water with vapor 2.Benzene.

Key words: **Clamshell Heat Exchanger; Analysis With Different Fluids;**

I. INTRODUCTION

Clamshell Heat Exchanger

Clamshell Heat exchangers are used in residential furnaces for purpose of room heating. Heat Exchangers are made of mirror image formed parts that are joined

together to form a clamshell. Heat Exchangers made of finless tube bent into a compact form are also popular. Standard indoor furnaces are generally made of cold-rolled steel. If the furnace is exposed to clean air and if the heat exchanger is dry, the material has a long life and does not easily corrode. Some problems of heat exchanger corrosion and failure have been encountered because of exposure to halogen ions in the incoming air with flue gas. Combustion air contamination with laundry bleach, cleaning solvents, halogenated hydrocarbon is common. Metallic coated material like aluminized steel or stainless steel are used for such application where corrosion resistant material is needed. In the case of condensing heat exchanger (secondary) a corrosion resistant material has to be used due to the presence of chloride compound in the condensate. It is designed such that it provides minimum resistance to flow. And normal expansion and contraction takes place with metal fatigue.

The material type is aluminized steel, which is aluminum –silicon alloy (5-11% Si) coating on low carbon steel sheets by the hot dip process. The Steel sheets are available in several designations.

- Commercial Steel
- Forming steel (FS)
- Deep Drawing steel (DDS)
- Extra Deep Drawing steel (EDDS)

This type of material is intended principally for heat resisting applications and for uses where corrosion resistance and heat are involved. Aluminized Steel Type is a continuously hot dip coated on both sides with an aluminum /silicon alloy coating. The hot dip process provides a tight metallurgical bond between the steel and alloy coating. This process results in a material with strength of steel and plus the corrosion protection of aluminum, and the synergistic heat protection of an aluminum /silicon alloy.

This material has superior performance than Zinc coated materials for resistance to atmospheric, salt spray and muffler condensate corrosion. It can produce parts containing simple bends to parts with extreme deep drawing .It has excellent heat reflectivity during exposure to temperature below 800°F(427°C), reflecting upto 80% of the radiant heat that impinges upon it. It is also an excellent heat resistant material effective to at least 1250°F.

Aluminized Steel Type coating contains approximately 91% aluminum and 9% silicon that is metallurgical bonded to low carbon steel .The hot dip process provides a tightly adherent, uniform coating on both sides of the product.

Problem Statement:

Clamshells are part of heat exchangers, which are being used in residential furnaces. The clamshell is subjected to alternating heating and cooling cycles, with a time span of 150seconds for each cycle. Due to this the clamshell is subjected to highly varying thermal stresses in short span of time. These stress variations develop thermal fatigue in the component and result in failure of the component. Firstly, the maximum and minimum thermal stresses that are developed in the clamshell during the heating and cooling cycle respectively have to be determined.

During heating cycle complete combustion of Methane gas in the presence of oxygen takes place in the burner. Carbon dioxide and water vapor are the products of combustion. These products of combustion flow into the heat exchanger for a time period of 150 seconds heating the clamshell heat exchanger. In this process of heating, thermal stresses are induced in the clamshell heat exchanger. The stress distribution in the clamshell after the heating cycle is determined by performing the following steps: -

- Gas flow Analysis to plot velocity, pressure and temperature distribution in gas flow region
- Thermal analysis of clamshell heat exchanger to plot temperature distribution in the clamshell after the gas flow. The temperature distribution in the gas flow region is used as input here.
- Structural analysis of clamshell heat exchanger to plot the thermal stress distribution in the clamshell. The temperature distribution in clamshell heat exchanger after the heating cycle is used as input here.

From this distribution the maximum thermal stress is obtained, which is used to calculate the fatigue life of the clamshell heat exchanger.

During the cooling cycle air flows over the heat exchanger for the next 150 seconds cooling the clamshell and heating the air. The clamshell is now cooled by the flow of air, thus inducing relatively lower thermal stresses when compared to heating cycle. The stress distribution in the clamshell after the cooling cycle is determined by performing the following steps: -

- Airflow analysis to plot the velocity, pressure and temperature distribution in the airflow region and temperature distribution in clamshell heat exchanger. The temperature distribution obtained in the clamshell heat exchanger after the heating cycle is specified as initial condition.
- Thermal analysis of clamshell heat exchanger to plot temperature distribution in the clamshell after the airflow.
- Structural analysis of clamshell heat exchanger to plot the thermal stress distribution in the clamshell. The temperature distribution in clamshell heat exchanger after the cooling cycle is used as input here.

From this distribution the minimum thermal stress is obtained, which is used to calculate the fatigue life of the clamshell heat exchanger.

Finally with the help of Modified Goodman Diagram the number of cycles under which the material is safe subjected to fatigue loading is calculated using the maximum and minimum thermal stresses obtained above.

II. LITERATURE REVIEW

Davis and Gill [1] considered the impact of divider conduction consequences for think about state laminar stream between the parallel plates (Poiseulle-couette stream). Expository arrangements are worked out to foresee the test perceptions of the hub conduction in the divider utilizing separate arrangement of the fluid stage and strong divider temperature fields. It has been watched that the parameters like Peclet number and the thickness to length proportion of the divider assume an imperative part in assurance the hub conduction impact. The divider conduction consequences for neighborhood Nusselt number and interface temperature dissemination in turbulent stream between the parallel plates are contemplated by **Sakakibara and Endoh [2]** both systematically and tentatively. As in the laminar stream it was watched that the Prandtl number, Reynolds number, proportion of conductivity of the divider to that of the liquid, thickness to length proportion of the divider where the essential parameters to decide the impact of the divider conduction. Conjugate warmth exchange from a surface mounted square to constrained convection wind stream with speed 1-7 m/s in a parallel plate channel was considered tentatively by **Nakayama and Park [3]**. Exploratory estimation of adiabatic divider temperature and adiabatic warmth exchange coefficients were utilized to represent the impact of warm wake shed from the square on the warmth exchange from the floor. The precision of the numerical expectation of the warm conductance for various warmth stream ways was demonstrated tentatively. The exploratory investigation of the divider temperature variances under the distinctive warm limit conditions in a rectangular channel was done by **Mosyak et al [4].** The aftereffects of the investigations are contrasted and existing trial and numerical information. The divider temperature fields are additionally analyzed with the reasonable warm structures. Notwithstanding the impact of warm passage locale on the divider temperature appropriation is likewise considered. It has been demonstrated that the divider temperature variances depend firmly on the sort of divider warm limit conditions. The conjugate warmth exchange issue for a round barrel with a warmed center area in low

Reynolds number stream has been contemplated numerically by **Suden [5].** The proportion of strong and liquid warm conductivity (λs/λf) has been found to incredibly impact the warmth exchange. **Webb and Ramadhyani [6]** have contemplated numerically the warmth exchange attributes for a steady property liquid moving through a parallel plate channel with stunned, transverse ribs and a consistent warmth transition along both the dividers. After a limited section length the stream turns out to be intermittently completely created. Calculations were completed in the completely created administration for various Reynolds numbers, Prandtl numbers and geometric courses of action. It has been demonstrated that noteworthy warmth exchange expansion is gotten for high Prandtl number liquids, for example, water. Furthermore conduction in the channel dividers is found to assume critical part in upgrading heat exchange. The numerical recreation of conjugate warmth exchange examination has not been accounted for enough in the writing. **Kasagi et al [7]** created two dimensional channel streams alongside shaky warmth conduction along the divider utilizing Stream astute Pseudo-vertical Motion (SVPM) show. Dissimilar to the common technique in light of Reynolds deterioration, the arithmetical articulations for three fluctuating speeds given by the model are straightforwardly brought into the overseeing conditions comes about. From the numerical consequences of insecure conjugate warmth exchange, the stastical amounts, for example, temperature difference, turbulent warmth transition and turbulent Prandtl number are gotten for liquids of different Prandtl numbers. The outcomes are both subjective and quantitative concurrence with the accessible information. It was watched that the close divider conduct of these amounts is firmly affected by the warm properties and thickness of the divider and the intelligible turbulent structures likewise assume an imperative part in the scalar transport process close to the divider. **Asako and Fagri [8]** have mimicked numerically the warmth exchange and liquid stream qualities of a laminar through a variety of warmed square pieces sent along one mass of parallel-plate channel. Warmth is created consistently at the base surface of the each piece. The reproduction showed that the surface temperature of each piece is practically uniform for high estimations of warm conductivity. Parametric examinations were likewise directed for different Reynolds number and different estimations of geometric and warmed range parameters. **Iaccarino et al [9]** have explored the impact of warm limit conditions on numerical warmth move expectations in rib-roughened sections. Results acquired utilizing consistent heatflux at the dividers and conjugate warmth exchange are contrasted with show how the distribution bubbles upstream and downstream of the rib effectsly affect the neighborhood warm exchange. Examination between numerical expectations, trial estimations and information connections demonstrate that the anticipated warmth exchange is extremely touchy to the kind of limit conditions utilized as a part of the numerical model. It has been demonstrated that a portion of the errors saw amongst trial and numerical information can be disposed of if conduction warm move in the rib is considered. **Adami et al [10]** updated a limited volume CFD answer for conjugate warmth exchange investigation. The redesign arrangement was approved against hypothetical outcomes on basic stream over level plate and film-cooled plate before applying a mind boggling stream issue on 3D film cooled cutting edge. Conjugate warmth exchange ponder for fast and high temperature applications are not found in writing. In clamshell warm exchanger the working temperature is amazingly high, it is fundamental to decide the temperature conveyance in the strong alongside the liquid. Cost of dull investigation is gigantic and then again the hypothetical forecast is practically incomprehensible for the many-sided quality of the stream and the mind boggling geometry of the clamshell warm exchanger. The numerical reenactment is by all accounts a practical and an option answer for the forecast of the liquid stream and temperature appropriation in clamshell warm exchanger.

III. METHODS AND MATERIALS

Introduction

The Thermal Stress analysis of clamshell heat exchanger is performed using ANSYS 15.0 flotran module. The analysis can be grouped under two steps as follows

Analysis of heating cycle

The complete combustion of Methane gas in the presence of oxygen takes place in the burner. Carbon dioxide and water vapor are the products of combustion. These products of combustion flow into the heat exchanger for a time period of 150 seconds heating the clamshell heat exchanger. The

- Calculation of velocity, pressure and temperature distribution in gas flow region
- Calculation of temperature distribution in clamshell heat exchanger using the temperature distribution in gas flow region as input.
- Calculation of thermal stress distribution in the clamshell heat exchanger using the temperature distribution in clamshell heat exchanger as input. From this stress distribution we will determine the maximum

thermal stress to calculate the number of cycles under which the material is safe subjected to fatigue loading.

Analysis of Cooling Cycle

In second step Air flows over the heat exchanger for 150 seconds cooling the clamshell and heating the air.

- Calculation of velocity, pressure and temperature distribution in the airflow region and temperature distribution in clamshell heat exchanger using the temperature distribution in the clamshell heat exchanger as initial condition.
- Calculation of temperature distribution in clamshell heat exchanger after the air flow
- Calculation of thermal stress distribution in the clamshell heat exchanger using the temperature distribution in clamshell heat exchanger as input. From this stress distribution we will determine the minimum thermal stress to calculate the number of cycles under which the material is safe subjected to fatigue loading.

Finally using the maximum and minimum thermal stress, we calculate the number of cycles under which the material is safe subjected to fatigue loading.

Flow Diagram Representation of Residential Heating Furnaces:

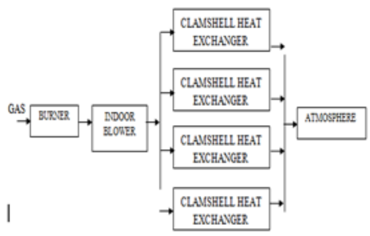


Figure shows gas flow through heat exchanger

Material Properties of Aluminized steel

Aluminized Steel Type is a continuously hot dip coated on both sides with aluminum /silicon alloy coating. The hot dip process provides a tight metallurgical bond between the steel and alloy coating. This process results in a material with strength of steel and plus the corrosion protection of aluminum, and the synergistic heat protection of an aluminum /silicon alloy. This material has superior performance than Zinc coated materials for resistance to atmospheric, salt spray and muffler condensate corrosion. It can produce parts containing simple bends to parts with extreme deep drawing .It has excellent heat reflectivity during exposure to temperature below 800˚F(427˚C), reflecting up to 80% of the radiant heat that impinges upon it. It is also an excellent heat resistant material effective up to at least 1250˚ F.

Aluminized Steel Type coating contains approximately 91% aluminum and 9% silicon that is metallurgical bonded to low carbon steel .The hot dip process provides a tightly adherent, uniform coating on both sides of the product.

Variation of specific Heat with Temperature

Temperature (f)	Specific Heat (btu/lb-f)
1350	**46.98**
1200	**44.892**
1050	**40.194**
800	**38.628**
680	**35.496**
500	**33.408**
320	**30.798**
120	**28.71**

Variation of Coefficient of thermal

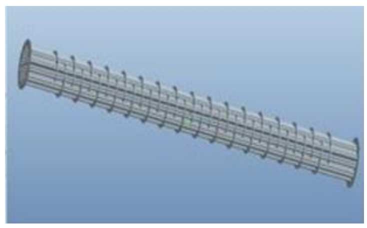
Expansion with Temperature

Temperature (F)	Coefficient of Thermal Expansion
1260	8.30E-06
1150	8.35E-06
900	8.00E-06
600	7.75E-06
500	7.50E-06
300	7.30E-06

Modeling & Meshing

The gas flow region is modeled in ANSYS15.0 using the modeling options in Preprocessor

Then it is meshed using the Hexahedral element in ANSYS i.e. FLUID142



Modelling of heat exchanger with outer shell

Meshing model of heat exchanger

IV. ANALYSIS AND RESULTS

1st case of water vapor flow

Analysis results of before design and findings

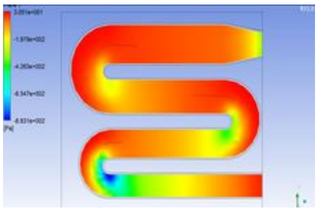


Figure shows pressure contours at flow points

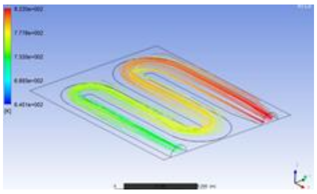


Figure shows temperature stream line

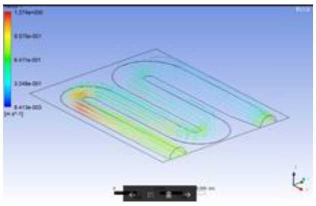


Figure shows velocity streamline

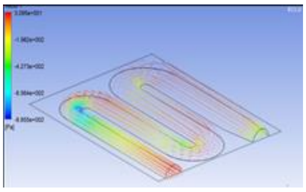


Figure shows pressure vectors

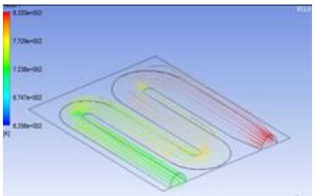


Figure shows temperature vector flow

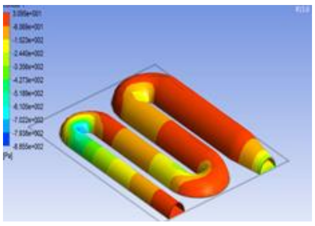


Figure shows Pressure variants of hot water liquid flow

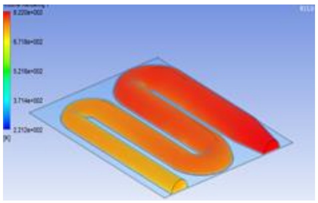


Figure shows the temperature flow

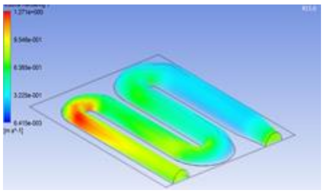


Figure shows velocity variants

Discussion:

The analysis shows the temperature distribution in the clamshell after the cooling cycle has been completed. The heat from the clamshell heat exchanger is being convicted to the air by forced convection. The air is being blown with the help of a blower. The air is being taken from the atmosphere and blown over the heat exchanger to get the desired hot air for room heating purpose.

The maximum temperature in the clamshell heat exchanger before cooling cycle is 1020˚Fat the entrance of the gas flow. After cooling cycle the maximum temperature of the clamshell is reduced to 805°F. And it is occurring at a distance from the entrance of the gas flow .The hot air as it proceeds over the heat exchanger it gets heated progressively. At the end of the heat exchanger the air gets hotter than the clamshell heat exchanger and some part of the heat from the air is transferred to the clamshell heat exchanger. Thereby heating the clamshell heat exchanger at the exit .Due to this the minimum temperature of the clamshell heat exchanger after cooling is greater than the before cooling. The maximum temperature difference in the clamshell after cooling is only around 110˚F. Hence the thermal gradients are less compared to the thermal gradients before the cooling cycle. The thermal stresses directly depend upon the thermal gradients. Therefore the thermal stresses induced after the cooling cycle are also lesser. The thermal stress distribution is obtained by performing the structural analysis with this obtained temperature distribution.

V. CONCLUSIONS

- The failure analysis of clamshell heat exchanger has been simulated using the principles of finite element methods and the analysis software ANSYS 15.0.
- The velocity, pressure and temperature distributions of both the gas flow and airflow

are plotted. The temperature and the thermal stress distribution in the clamshell heat exchanger after heating and cooling cycles are plotted.

- The large thermal gradient existing in the region near the first bend is observed to be the critical parameter for the failure of the clamshell heat exchanger. The thermal stresses induced after the heating cycles are very high when compared to the thermal stresses induced after the cooling cycle. Hence the large stress variations are occurring in the small time span of 150 seconds. Due to these stress variations, thermal fatigue is induced in the clamshell heat exchanger. Finally the clamshell heat exchanger is failing after 9399.37 cycles due to thermal fatigue near the first bend region.
- The thermal gradient in that region is the critical parameter for increasing the fatigue life of the component. The design should be modified such that the thermal gradients are small. The thermal gradient can be reduced by increasing the heat transfer area near the first bend. Quantity of heat-transferred increases with the increase in the area of heat transfer .The temperature rise in this region is reduced due to the increased quantity of heat transfer from the clamshell. Thereby developing small thermal gradient in that region. The area of heat transfer can be increased by increasing the radius of the first bend, thereby facilitating for more heat to be transferred and developing small thermal gradients.

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